PE15.1
Attachment C

TransformTO

Technical Backgrounder
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SSG SUSTAINABILITY SOLUTIONS GROUP

whatIf?

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1.0 Introduction

This summary paper provides a high-level overview of the process and approach to building an energy and emissions model for the City of Toronto for *TransformTO: Modelling Toronto's Low Carbon Future.*

2.0 About the model

CityInSight is used as the main modelling tool. CityInSight is a comprehensive energy, emissions and finance model developed by Sustainability Solutions Group (SSG) and whatIf? Technologies Inc. (whatIf?) . The model builds on SSG's ten years of experience applying an earlier model called GHGProof, and whatIf?'s thirty years of experience building provincial and national models of energy systems.

CityInSight uses the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*, an international standard for greenhouse gas emissions as an accounting framework.

3.0 Stages of modelling

The modelling stages include:

Stage	Method
1. Data collection	A data request is compiled and data is collected from various sources. Assumptions are identified to supplement any gaps in observed data. Documentation of data, methods and assumptions ensures transparency of data and assumptions used.
2. Model calibration and baseline	The model is built from the ground up starting with people, putting people in dwellings, putting jobs in buildings, developing a surface model of the buildings, identifying how people move around and then undertaking other analysis on waste, industry and land-use. At each stage the bottom-up model is calibrated against observed data, and a baseline year is established.
3. Build-as-planned (BAP) scenario	Existing city projections are incorporated into the model where available. Other projections for regional, provincial and national policy are incorporated where available. Objectives for other existing policies are identified and translated into the model.
4. Low carbon scenario	Key levers are identified and adjusted iteratively to identify a pathway to achieve the long term low carbon objectives for the City.

4.0 Accounting Framework

The model uses the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories as the underlying accounting framework.

Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)

The GPC is the result of an effort to standardise city-scale inventories by the World Resources Institute, C40 Cities Climate Leadership Group and ICLEI – Local Governments for Sustainability (ICLEI).[1]

The GPC provides a robust framework for accounting and reporting city-wide greenhouse gas emissions. It seeks to:

- Help cities develop a comprehensive and robust greenhouse gas inventory in order to support climate action planning;
- Help cities establish a base year emissions inventory, set reduction targets, and track their performance;
- Ensure consistent and transparent measurement and reporting of greenhouse gas emissions between cities, following internationally recognized greenhouse gas accounting and reporting principles;
- Enable city inventories to be aggregated at subnational and national levels;
- Demonstrate the important role that cities play in tackling climate change, and facilitate insight through benchmarking – and aggregation – of comparable data.

To date, more than 100 cities across the globe have used the GPC (current and previous versions) to measure their greenhouse gas emissions.

The GPC has been adopted by the following programs and initiatives:

- The Compact of Mayors (CoM)[2] is an agreement led by city networks to undertake a transparent and supportive approach to reduce city emissions and enhance resilience to climate change. CoM cities are required to measure and report greenhouse gas emissions using the GPC. The City of Toronto is currently committed as a Compact of Mayors city.

1 http://www.ghgprotocol.org/city-accounting

2 http://www.compactofmayors.org/

- carbonn Climate Registry is the common, publicly available repository for the Compact of Mayors. It provides standard reporting templates to help cities report their GHG emissions using the GPC. Currently about 300 cities have reported their emissions using carbonn Climate Registry.
- CDP runs the world's largest environmental reporting platform. More than 5,000 companies, 200 cities, and 12 states and regions use CDP's platform every year to report on their environment-related data, including GHG emissions, climate risks, water risks, and economic opportunities. CDP serves as the official reporting platform for C40 cities, the Compact of Mayors and the Compact of States and Regions. CDP supports cities in reporting their emissions using the GPC. The City of Toronto currently reports to CDP.

5.0 Accounting and Reporting Principles

The GPC is based on the following principles in order to represent a fair and true account of emissions:

- **Relevance:** The reported GHG emissions shall appropriately reflect emissions occurring as a result of activities and consumption within the city boundary. The inventory will also serve the decision-making needs of the city, taking into consideration relevant local, subnational, and national regulations. Relevance applies when selecting data sources, and determining and prioritizing data collection improvements.
- **Completeness:** All emissions sources within the inventory boundary shall be accounted for. Any exclusions of sources shall be justified and explained.
- **Consistency:** Emissions calculations shall be consistent in approach, boundary, and methodology.
- **Transparency:** Activity data, emissions sources, emissions factors and accounting methodologies require adequate documentation and disclosure to enable verification.
- **Accuracy:** The calculation of GHG emissions should not systematically overstate or understate actual GHG emissions. Accuracy should be sufficient enough to give decision makers and the public reasonable assurance of the integrity of the reported information. Uncertainties in the quantification process should be reduced to the extent possible and practical.

6.0 Assessment Boundary

6.1 Geographic boundary

The geographic boundary for this assessment consists of the municipal boundary of the City of Toronto as shown in Figure 1.

Figure 1. Assessment boundary for City of Toronto.

6.2 Time period of assessment

- The assessment will cover the years from 2011 to 2050.
- The year 2011 will be used as the baseline year within the model. This is primarily based on:
  - The model requires the calibration of a base year system state (initial conditions) using as much observed data as possible in order to develop and internally consistent snapshot of the city.
  - A key data source for the model is census data. At the time of modelling, the last census year for which data is available is 2011.
  - In addition, the Transportation Tomorrow Survey and the long range transportation modelling conducted by the City follow the census year 2011.
  - 2011 represents the most recent year for which significant data source overlap occurs and therefore the best choice for model calibration and baseline.
- 5 year increments are modelled from the 2011 baseline year. 2016 will represent the first simulation period/year.
- Projections will extend to 2050.
- Due to the 5-yr increment, the last simulation year will be 2051. Results will be interpolated back for 2050.

6.3 Energy and emissions structure

The total energy for a community is defined as the sum of the energy from each of the aspects:

$$Energy_{city} = Energy_{transport} + Energy_{buildings} + Energy_{wastegen}$$

Where:

$Energy_{transport}$ is the movement of goods and people.
$Energy_{buildings}$ is the generation of heating, cooling and electricity.
$Energy_{wastegen}$ is energy generated from waste.

The total GHG for a community is defined as the sum of the GHG from each of the

aspects: Where:

$$GHG_{land\ use} = GHG_{transport} + GHG_{energygen} + GHG_{waste} + GHG_{agriculture} + GHG_{forest} + GHG_{landconvert}$$

$GHG_{transport}$ is the movement of goods and people. $GHG_{energygen}$ is the generation of heat and electricity. GHG_{waste} is liquid and solid waste produced.
$GHG_{agriculture}$ is the production of food.
GHG_{forest} is the area of forest land.
$GHG_{landconvert}$ is the area of land in natural or modified conditions.

6.4 Scope

The inventory will include Scope 1 and 2, and some aspects of Scope 3 (see Figure 2).

Scope	Definition
1	All GHG emissions from sources located within the city boundary.
2	All GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

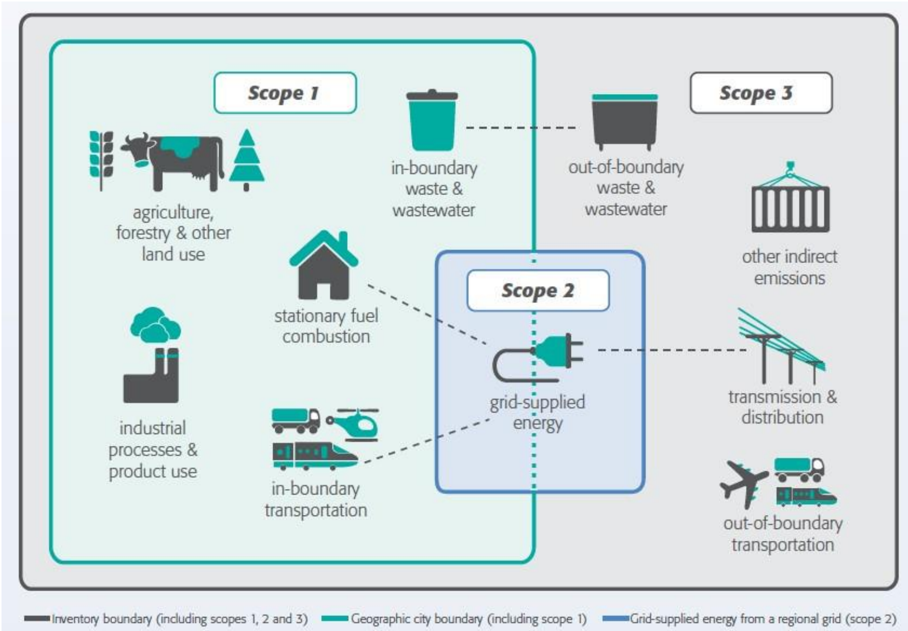

Figure 2. GPC scope boundaries.

6.5 Greenhouse gases

The inventory addresses carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20). Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6) and nitrogen triflouride (NF3) are not included. Emissions are expressed in CO2 equivalents per the assumptions in Table 1.

Table 1. Global Warming Potentials for selected greenhouse gases.

Gas	CO2 equivalent	Notes
CO_2	1	
CH_4	34	These have been updated in the IPCC 5th Assessment Report to include climate-carbon feedback.
N_2O	298	These have been updated in the IPCC 5th Assessment Report to include climate-carbon feedback.

7.0 Previous Inventories

The City of Toronto has completed previous inventories in 2011, 2012 and 2013, available at the City of Toronto's website.[3]

3 http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=3a65fbfa98491410VgnVCM10000071d60f89RCRD

8.0 About CityInSight

CityInSight is an integrated energy, emissions and finance model developed by Sustainability Solutions Group and whatIf? Technologies. It is an integrated, multi-fuel, multi-sector, spatially-disaggregated energy systems, emissions and finance model for cities. The model enables bottom-up accounting for energy supply and demand, including renewable resources, conventional fuels, energy consuming technology stocks (e.g. vehicles, appliances, dwellings, buildings) and all intermediate energy flows (e.g. electricity and heat).

Energy and GHG emissions are derived from a series of connected stock and flow models, evolving on the basis of current and future geographic and technology decisions/assumptions (e.g. EV penetration rates). The model accounts for physical flows (i.e. energy use, new vehicles by technology, vehicle kilometres travelled) as determined by stocks (buildings, vehicles, heating equipment, etc).

CityInSight incorporates and adapts concepts from the system dynamics approach to complex systems analysis. For any given year within its time horizon, CityInSight traces the flows and transformations of energy from sources through energy currencies (e.g. gasoline, electricity, hydrogen) to end uses (e.g. personal vehicle use, space heating) to energy costs and to GHG emissions. An energy balance is achieved by accounting for efficiencies, conservation rates, and trade and losses at each stage in the journey from source to end use.

Table 2. Characteristics of CityInSight.

Characteristic	Rationale
Integrated	CityInSight is designed to model and account for all sectors that relate to energy and emissions at a city scale while capturing the relationships between sectors. The demand for energy services is modelled independently of the fuels and technologies that provide the energy services. This decoupling enables exploration of fuel switching scenarios. Physically feasible scenarios are established when energy demand and supply are balanced.
Scenario-based	Once calibrated with historical data, CityInSight enables the creation of dozens of scenarios to explore different possible futures. Each scenario can consist of either one or a combination of policies, actions and strategies. Historical calibration ensures that scenario projections are rooted in observed data.
Spatial	The configuration of the built environment determines the ability of people to walk and cycle, accessibility to transit, feasibility of district energy and other aspects. CityInSight therefore includes a full spatial dimension that can include as many zones - the smallest areas of geographic analysis - as are deemed appropriate. The spatial component to the model can be integrated with City GIS systems, land-use projections and transportation modelling.
GHG reporting framework	CityInSight is designed to report emissions according to the GHG Protocol for Cities (GPC) framework and principles.
Economic impacts	CityInSight incorporates a full financial analysis of costs related to energy (expenditures on energy) and emissions (carbon pricing, social cost of carbon), as well as operating and capital costs for policies, strategies and actions. It allows for the generation of marginal abatement curves to illustrate the cost and/or savings of policies, strategies and actions.

8.1 Model Structure

The major components of the model, and the first level of modelled relationships (influences), are represented by the blue arrows in Figure 3. Additional relationships may be modelled by modifying inputs and assumptions

- specified directly by users, or in an automated fashion by code or scripts running "on top of" the base model structure. Feedback relationships are also possible, such as increasing the adoption rate of non-emitting vehicles in order to meet a particular GHG emissions constraint.

The model is spatially explicit. All buildings, transportation and land use data are tracked within the model through a GIS platform, and by varying degrees of spatial resolution. Where applicable, a zone type system can be applied to break up the city in smaller configurations. This enables consideration of the impact of land-use patterns and urban form on energy use and emissions production from a baseline year to future dates using GIS-based platforms. CityInSight's GIS outputs can be integrated with city mapping systems.

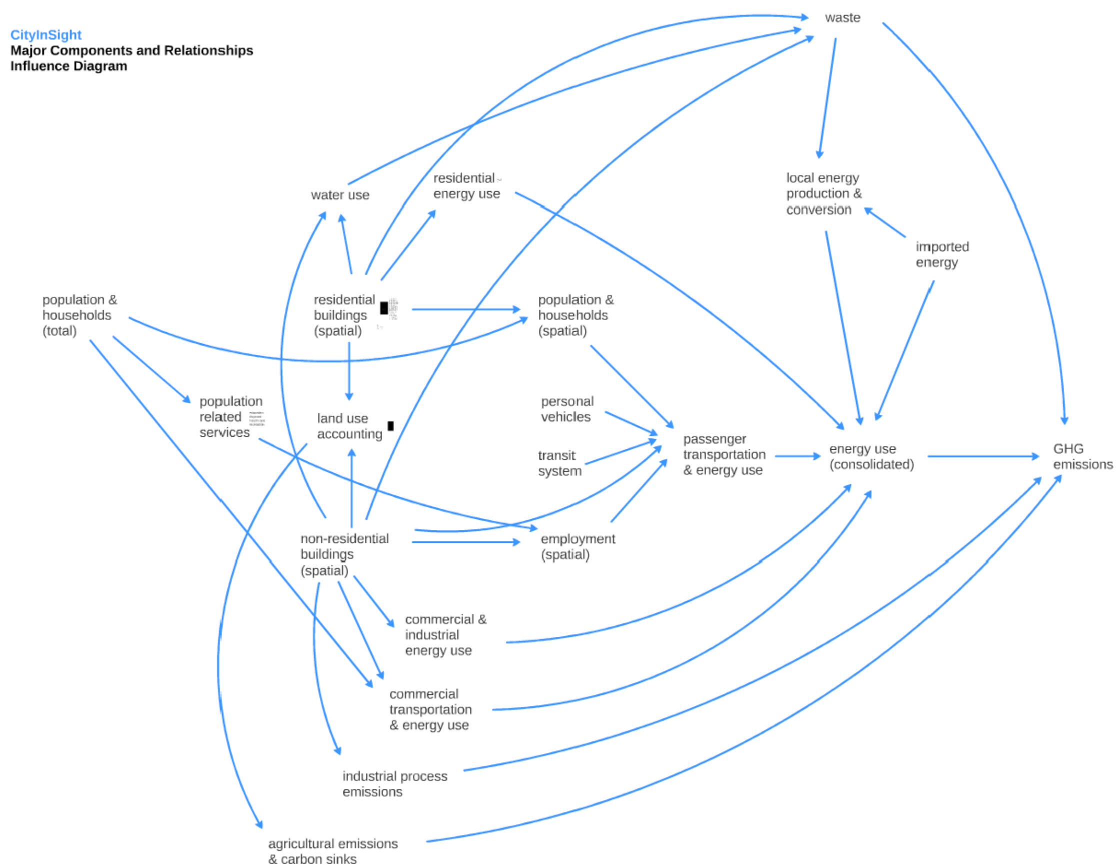

Figure 3. Representation of CityInSight's structure.

8.2 Stocks and flows

For any given year various factors shape the picture of energy and emissions flows, including: the population and the energy services it requires; commercial floorspace; energy production and trade; the deployed technologies which deliver energy services (service technologies); and the deployed technologies which transform energy sources to currencies (harvesting technologies). The model makes an explicit mathematical relationship between these factors - some contextual and some part of the energy consuming or producing infrastructure - and the energy flow picture.

Some factors are modelled as stocks - counts of similar things, classified by various properties. For example, population is modelled as a stock of people classified by age and gender. Population change over time is projected by accounting for: the natural aging process, inflows (births, immigration) and outflows (deaths, emigration). The fleet of personal use vehicles, an example of a service technology, is modelled as a stock of vehicles classified by size, engine type and model year - with a similarly-classified fuel consumption intensity. As with population, projecting change in the vehicle stock involves aging vehicles and accounting for major inflows (new vehicle sales) and major outflows (vehicle discards). This stock-turnover approach is applied to other service technologies (e.g. furnaces, water heaters) and also harvesting technologies (e.g. electricity generating capacity).

8.3 Sub-models

Population and demographics

City-wide population is modelled using the standard population cohort-survival method, disaggregated by single year of age and gender. It accounts for various components of change: births, deaths, immigration and emigration. The age structured population is important for analysis of demographic trends, generational differences and implications for shifting energy use patterns.

Residential buildings

Residential buildings are spatially located and classified using a detailed set of 30+ building archetypes capturing footprint, height and type (single, double, row, apt. high, apt. low), in addition to year of construction. This enables a “box” model of buildings and the estimation of surface area. Coupled with thermal envelope performance and degree-days the model calculates space conditioning energy demand independent of any particular space heating or cooling technology and fuel. Energy service demand then drives stock levels of key service technologies (heating systems, air conditioners, water heaters). These stocks are modelled with a stock-turnover approach capturing equipment age, retirements, and additions - exposing opportunities for efficiency gains and fuel switching, but also showing the rate limits to new technology adoption and the effects of lock in. Residential building archetypes are also characterized by number of contained dwelling units, allowing the model to capture the energy effects of shared walls but also the urban form and transportation implications of population density.

Non-residential buildings

These are spatially located and classified by a detailed use/purpose-based set of 50+ archetypes, and the floorspace of these non-residential building archetypes can vary by location. Non-residential floorspace produces waste and demand for energy and water, and also provides an anchor point for locating employment of various types.

Spatial population and employment

City-wide population is made spatial by allocation to dwellings, using assumptions about persons-per-unit by dwelling type. Spatial employment is projected via two separate mechanisms: population-related services and employment, which is allocated to corresponding building floorspace (e.g. teachers to school floorspace); and floorspace-driven employment (e.g. retail employees per square metre).

Passenger Transportation

The model includes a spatially explicit passenger transportation sub-model that responds to changes in land use, transit infrastructure, vehicle technology, travel behavior change and other factors. Trips are divided into four types (home-work, home-school, home-other, and non-home-based), each produced and attracted by different combination of spatial drivers (population, employment, classrooms, non-residential floorspace). Trips are distributed - that is, trip volumes are specified for each zone of origin and zone of destination pair. For each origin-destination pair trips are shared over walk/bike (for trips within the walkable distance threshold), public transit (for trips whose origin and destination are serviced by transit) and automobile. Following the mode share step, along with a network distance matrix, a projection of total personal vehicles kilometres travelled (VKT) is produced. The energy use and emissions associated with personal vehicles is calculated by assigning VKT to a stock-turnover personal vehicle model. All internal and external passenger trips are accounted for and available for reporting according to various geographic conventions

Waste

Households and non-residential buildings generate solid waste and wastewater, and the model traces various pathways to disposal, compost and sludge including those which capture energy from incineration and recovered gas. Emissions accounting is performed throughout the waste sub-model.

Energy flow and local energy production

Energy produced from primary sources (e.g. solar, wind) is modelled alongside energy converted from imported fuels (e.g. electricity generation, district energy, CHP). As with the transportation sub-model, the district energy supply model has an explicit spatial dimension and represents areas served by district energy networks

Finance and employment

Energy related financial flows and employment impacts - while not shown explicitly in Figure 3 - are captured through an additional layer of model logic. Calculated financial flows include the capital, operating and maintenance cost of energy consuming stocks and energy producing stocks, including fuel costs. Employment related to the construction of new buildings, retrofit activities and energy infrastructure is modelled.

9.0 Scenario Development

CityInSight is designed to support the use of scenarios as a mechanism to evaluate potential futures for communities. A scenario is an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome. A good set of scenarios is both plausible and surprising but scenarios can also be misleading if, for example, there are too few so that one scenario is ‘‘good’’ and the other ‘‘bad”.

Another consideration is to ensure that the name of the scenario does not bias the audience. Lastly, scenarios must represent serious considerations defined not only by planning staff, but also by community members.

9.1 Build-as-planned scenario

A reference scenario (also known as a build-as-usual or build as planned scenario) was developed and projects to 2050 by identifying what would happen in the absence of any additional policy measures.

9.1.1 Methodology

1. Calibrate model and develop 2011 baseline using observed data and filling in gaps with assumptions where necessary;
2. Input existing projected quantitative data to 2050 where available: Population, employment & households projections from City by transport zone; Build out (buildings) projections from City by transport zone; Transport modelling from City;
3. Where quantitative projections are not carried through to 2050 (eg. completed to 2041), extrapolate the projected trend to 2050;
4. Where specific quantitative projections are not available, develop projections through:
5. Analysing current on the ground action in the City (reviewing actions plans, engagement with staff etc.), and where possible, quantifying the action;
6. Analysing existing policy that has potential impact for the city, and where possible, quantifying the potential impact.

9.1.2 Data & assumptions

Category	Data source	Description
Population	Strategic Regional Research Alliance projections developed for SmartTrack; *Low population projections without Smart Track influence scenario.*	703,000 to 1,062,000 addition people by 2041.
Employment	Strategic Regional Research Alliance projections developed for SmartTrack; *Medium employment projections without Smart Track influence scenario.*	Employment projections to 2041; 476,000 to 505,000 additional jobs. Location of these jobs is also indicated by traffic zone.
Building projections	Strategic Regional Research Alliance projections developed for SmartTrack; *Low (pop) & Med (emp) without Smart Track influence scenario.* Internal City projections indicate location of population, households and jobs by traffic zone.	Residential and commercial building locations are indicated.

Building energy performance	Toronto Atmospheric Fund projections for the Green Standard; Net zero by 2030 (Ontario Climate Action Plan)	Incremental EUIs until 2030 for residential and commercial buildings. This target is consistent with the Ontario Climate Action Plan.
Energy performance of residential stocks	CanESS Social housing and apartment retrofits (Ontario Climate Action Plan)	CanESS is calibrated to National Energy Board projections. Projections under the Ontario Climate Action Plan are not clear.
Transit system	SmartTrack projections; *Low (pop) & Med (emp) without Smart Track influence scenario.*	Transit projections
Transportation modes and VKT	OD Matrices from Transportation Tomorrow Survey (DMG)	
Transport fuels	Renewable fuels standard (Ontario Climate Action Plan)	Currently the requirements are not clear.
Light duty vehicle efficiency and stocks	CanESS (Ontario Climate Action Plan)	CanESS is calibrated to National Energy Board projections to 2041.
Commercial transport	CanESS	
Electricity system	Long term electricity plan	Residential, commercial and industrial electricity intensities until 2031. Fuel costs and fuel mix until 2031.
Decentralised energy supply	City of Toronto Preliminary Node Scan of Potential District Energy Implementation; District energy framework (forthcoming); City of Toronto Hydro Solar PV Program	
Natural gas system	IESO projections	Internal modelling by whatIf? Technologies.
Energy generation technology costs	Long term electricity plan	Energy generation technology costs until 2031.
Solid waste	Final Long Term Waste Management Strategy	70% residential & ICI waste diversion rate by 2026. Diversion projections until 2026. Capital costs until 2052.
Wastewater	City specific data	

9.2 Low carbon scenario

CityInSight is designed to project how the energy flow picture and emissions profile will change in the long term by modelling potential change in the context (e.g. population, development patterns), projecting energy services demand intensities, and projecting the composition of energy system infrastructure, often with stocks.

Policies, actions and strategies

Throughout the CityInSight accounting framework there are input variables - for user assumptions and projections - which collectively comprise an interface to controlling the physical trajectory of the urban energy system and resultant emissions. Different settings for these inputs can be interpreted as alternative behaviours of various actors or institutions in the energy system (e.g. households, various levels of government, industry, etc). This interface can be directly set or controlled by the model user, to create "what if" type scenarios. The modelling platform upon which CityInSight is built allows for a "higher layer" of logic to operate at this physical- behavioural interface, in effect enabling a flexible mix-and-match approach to behavioral models which connect to the same constraining physical model. CityInSight is able to explore a wide variety of policies, actions and strategies. The resolution of CityInSight enables the user to apply scenarios to specific neighbourhoods, technologies, building or vehicle types or eras, and configurations of the built environment.

9.2.1 Methodology

1. Develop list of potential actions and strategies from consultant expertise, input from city staff and community engagement

2. Identify the technological potential of each action (or group of actions) to reduce energy and emissions by quantifying actions:

- Firstly if the action or strategy specifically incorporates a projection or target; or,
- Secondly, if there is a stated intention or goal, review best practices and literature to quantify that goal;
- Thirdly, identify any actions that are either overlapping and/or include dependencies on other actions;

3. Translate the actions into quantified assumptions over time;

4. Apply the assumptions to relevant sectors in the model to develop a low carbon scenario (i.e. apply the technological potential of the actions to the model);

5. Analyze results of the low carbon scenario against the overall 80x50 target;

6. If the target is not achieved, identify variables which can be scaled up and provide a rationale for doing so;

- Iteratively adjust variables to identify a pathway to 80x50;
- Develop marginal abatement curve for low carbon scenario;
- Define criteria to evaluate low carbon scenario (i.e identify criteria for multi-criteria analysis);
- Prioritize actions of low carbon scenario through multi-criteria analysis (along with other criteria eg. health, prosperity etc.);

7. Revise scenario to reflect prioritisation for final low carbon scenario, removing and scaling the level of ambition of actions according to the evaluation results.

10.0 Addressing Uncertainty

There is extensive discussion of the uncertainty in models and modelling results. The assumptions underlying a model can be from other locations or large data sets and do not reflect local conditions or behaviours, and even if they did accurately reflect local conditions, it is exceptionally difficult to predict how those conditions and behaviours will respond to broader societal changes and what those broader societal changes will be (the "unknown unknowns").

An analysis of land-use models used to assess climate change impacts for Sydney, Australia, emphasised that the models should be used only for scenario testing and not forecasting because of limits to the possible precision. The importance of this point is demonstrated by the fact that the models considered in this analysis can generate a range of outcomes from the same starting point (Oydell et al., 2007, pg. 10).

The modelling approach identifies four strategies for managing uncertainty applicable to community energy and emissions modelling:

1. **Sensitivity analysis:** From a methodological perspective, one of the most basic ways of studying complex models is sensitivity analysis, quantifying uncertainty in a model's output. To perform this assessment, each of the model's input parameters is described as being drawn from a statistical distribution in order to capture the uncertainty in the parameter's true value (Keirstead, Jennings, & Sivakumar, 2012).

» Approach: Each of the variables will be increased by 10-20% to illustrate the impact that an error of that magnitude has on the overall total.

2. **Calibration:** One way to challenge the untested assumptions is the use of 'back-casting' to ensure the model can 'forecast' the past accurately. The model can then be calibrated to generate historical outcomes, which usually refers to "parameter adjustments" that "force" the model to better replicate observed data.

» Approach: Variables for which there are two independent sources of data are calibrated in the model. For example, the model calibrates building energy use (derived from buildings data) against actual electricity data from the electricity distributor.

3. **Scenario analysis:** Scenarios are used to demonstrate that a range of future outcomes are possible given the current conditions that no one scenario is more likely than another.

» Approach: The model will develop a reference scenario.

4. **Transparency:** The provision of detailed sources for all assumptions is critical to enabling policy-makers to understand the uncertainty intrinsic in a model.

» Approach: The assumptions and inputs are presented in this document.